

# **Understand the Air-Sea Coupling Processes in High Wind Conditions Using a Synthesized Data Analysis/modeling Approach**

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## **LONG-TERM GOAL**

The long-term goal of this project is to understand the air-sea interaction processes in the coastal region in high-wind conditions and to improve the boundary layer and surface flux parameterizations for high-resolution mesoscale model (COAMPS) in high-wind conditions.

## **OBJECTIVES**

The objectives of this year's work were to understand the oceanic response to the Tehuano event through a 1-d ocean mixed layer model forced by COAMPS surface fluxes.

## **APPROACH**

The work in FY08 focused on simulating and analyzing observed oceanic response to the gap wind event. In FY07, the observational study focused on oceanic response from ocean temperature measurements by satellites, this analysis extended to the response of the ocean mixed layer using the AXBTs measurements from GOTEX experiment. In addition, the single column ocean mixed layer (OML) model simulations were made for the entire COAMPS inner domain with surface forcing from COAMPS. Initial simulations of the OML were made in FY07 as part of a student thesis work. The coding was thoroughly checked for errors/modifications in FY08 and further analyses were made using results from the new simulations in FY08.

In addition, we worked with Dr. Shouping Wang and Xiaodong Hong on possible improvements of COAMPS simulation for the GOTEX cases and 3-D full ocean simulations.

## **WORK COMPLETED**

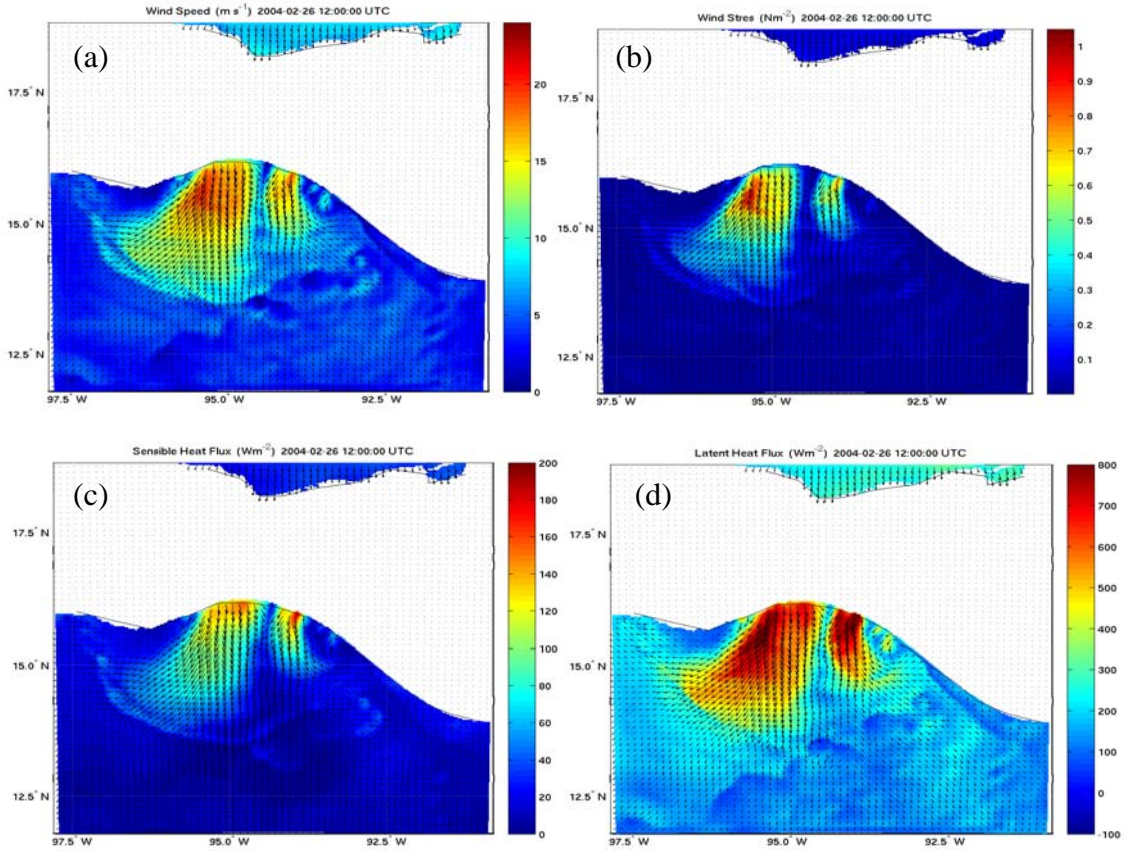
1. Full analyses of the evolution of the ocean mixed layer under the influence of the gap outflow using the AXBT measurements during GOTEX. This analysis also provided the initial condition for OML simulations.
2. A re-design of the coupling technique between the COAMPS results and the simulation of the OML forced by COAMPS surface fluxes. The new design of the running script should ensure error-free input and output in the OML simulations for multiple grids.
3. Simulations of the upper ocean response to high-wind gap event forcing from COAMPS. Spatial variations of the upper ocean were examined within the entire COAMPS domain.

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4. Design and analyses of roles of surface wind shear and surface heat flux forcing for the mixed layer development during the Tehuano event.
5. Analyses of the sensitivity of the upper ocean response to model initial condition and upwelling to determine the limitations of the single column model simulation for a large spatial domain.

## RESULTS

**COAMPS forcing to the ocean mixed layer model:** COAMPS simulation of the Tehuano event on Feb. 26, 2004 is used to force the NPS mixed layer model to examine the upper ocean response to the gap outflow. Figure 1 shows the spatial variation wind speed, surface stress, sensible and latent heat flux in the GoT region about 12 hours after the gap winds moved over the coastal water. Compared to the satellite observed gap outflow development, the western progression of the leading edge, and the wind speeds matched the outflow of the satellite imagery and the aircraft measured wind, while COAMPS simulations did not match the progression in the southward and southeastward part of the



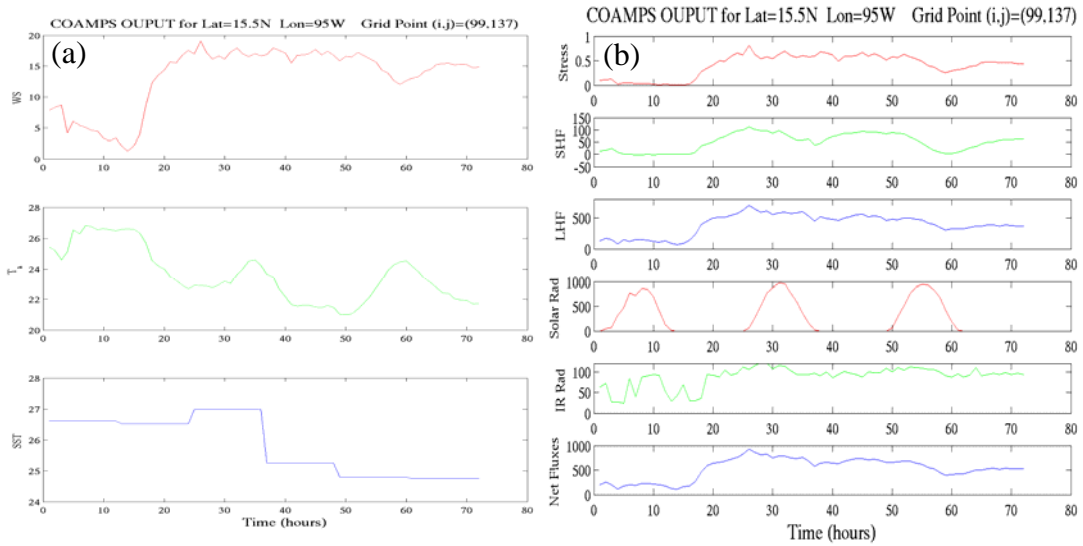
**Figure 1. COAMPS simulated fields on 26 February at 12Z. All variables are displayed with the 10 m wind vector. (a) wind speed ( $\text{ms}^{-1}$ ); (b) wind stress contours (in  $\text{Nm}^{-2}$ ); (c) sensible heat flux; and (d) latent heat flux. Wind stress, sensible heat flux, and latent heat flux were used to drive the ocean mixed layer model.**

outflow, where the maximum wind jet core appears almost two degrees north compared to that seen from the scatterometer winds at the same longitude. The highest winds (Fig. 1a) peak at a magnitude of

$22 \text{ ms}^{-1}$  and occurred just offshore downstream of the gap. The COAMPS wind field also shows the existence of another smaller outflow to the south east side of the main gap outflow. This less extensive outflow is likely caused by the rising terrain east of Chivela Pass that forms a smaller pass to the west (the Chiapas). The surface stress shows a spatial distribution similar to the mean wind.

Sensible heat flux experiences strong diurnal variation. Here we find the enhanced sensible heat flux behind the outflow front with the maximum at the mouth of the GoT. The sensible heat flux can reach to a maximum of  $160 \text{ Wm}^{-2}$ . There is also significantly larger latent heat flux to the atmosphere along the western boundary of the main outflow compared to the rest of the outflow. This feature coincides with the drier air descending from higher terrain. Also, the secondary Chiapas outflow is drier and is seen to produce a much larger latent heat flux. Another feature of the latent heat flux is the apparent local maximum located over the region of significant SST gradient as the flow moves over the sea.

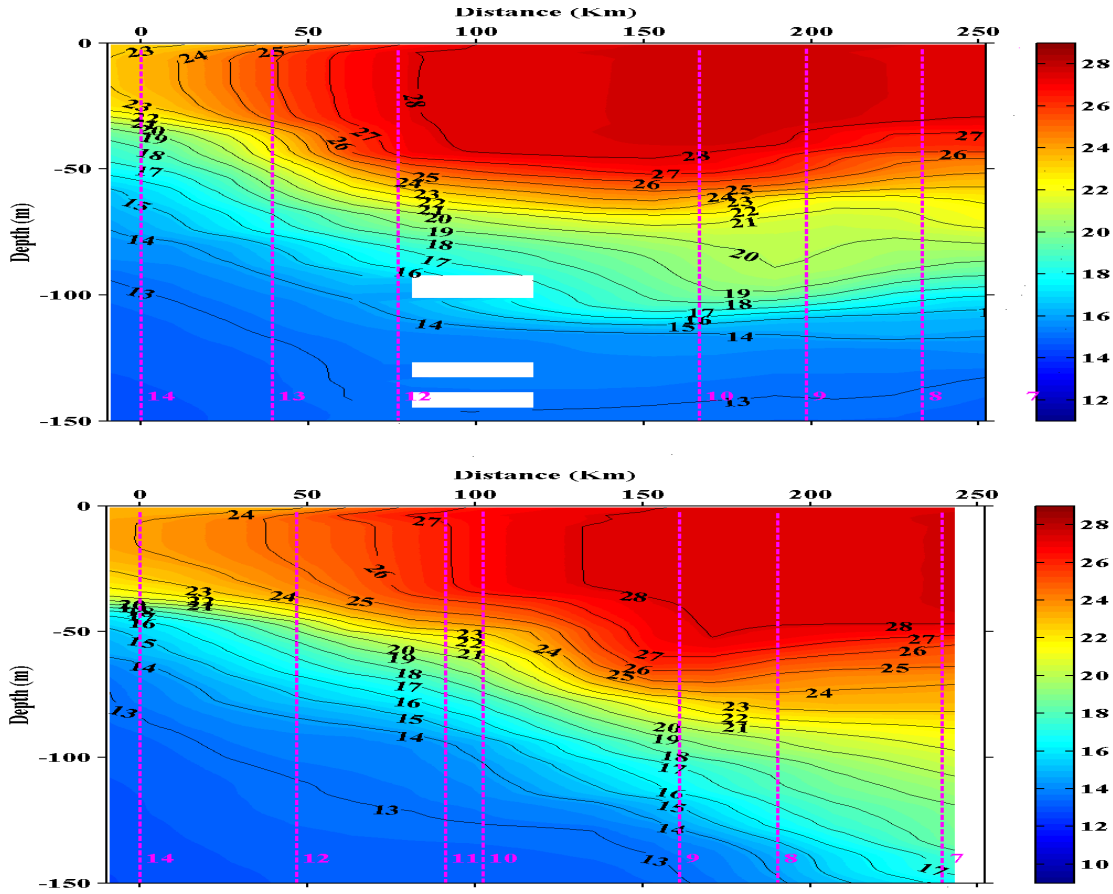
Figure 2 shows the time evolution (starting at 12Z of Feb 25, 2004) of the ocean mixed forcing from COAMPS at a single point close to the predicted jet core near the coast. The onset of gap wind at this location is clearly seen at hour 16 (02Z of 26 Feb, 2004), where surface stress increased from nearly zero to about  $0.6 \text{ Nm}^{-2}$ , 8 hours later at hour 24. During the same period, sensible heat flux increased from 0 to about  $90 \text{ Wm}^{-2}$  and latent heat flux increased from 120 to  $650 \text{ Wm}^{-2}$ . As a result, the net heat flux, the sum of sensible, latent, and IR heat fluxes, increased from 120 to  $770 \text{ Wm}^{-2}$ . The stress and heat flux decreased at hour 60 (00Z of Feb 28, 2004) although all variables are still higher than those prior to the onset of the high wind condition. It is also noted that the sensible and latent heat fluxes both went through slight diurnal variation during event. This is consistent with the diurnal variation of air temperature (Figure 2a). On the contrast, COAMPS SST remains constant within each 12 hour period, although it shows cooling at hour 36.



**Figure 2.** An example of the COAMPS forcing for the OML. From top to bottom, the panels show (a) wind speed ( $\text{m s}^{-1}$ ), surface air temperature ( $^{\circ}\text{C}$ ), and SST ( $^{\circ}\text{C}$ ); (b) the surface wind stress (in  $\text{Nm}^{-2}$ ), sensible heat flux (SHF, in  $\text{Wm}^{-2}$ ), latent heat flux (LHF, in  $\text{Wm}^{-2}$ ), solar irradiance (Solar Rad. in  $\text{Wm}^{-2}$ ), net longwave irradiance (IR Rad. in  $\text{Wm}^{-2}$ ), and the net heat flux (net fluxes, in  $\text{Wm}^{-2}$ ).

**Observed mixed layer and thermocline structure:** Results from AXBT measurements on two days during the gap wind event are presented in Fig. 3 where both plots use the same starting point about 100 km south from the mouth of the gulf. The two drop trajectories were close enough to warrant

inter-comparison between the two. From the satellite measured SST variation over a large area, it is seen that the AXBT trajectory went through a region with sharp SST gradient with SST increase of 3 °C within a 50 km distance. The AXBT measurements from both days show deeper mixed layer in the warm water patch. Since the AXBT drops on the first day (Fig. 3a) were made about 20 hours after the onset of Tehuano, its effects are already present in Fig. 3a. However, comparing between Fig. 3a and 3b, we can identify the continued effects of the gap event. Within the 24 hour period, the Tehuano appeared to affect the thermocline and the mixed layer in the cold water region the most where we found a drop of about 0.7 to 2.3 °C for temperature at 50 m below the surface in the cool water region. Temperature at 50 m depth increased by about 1 °C as the mixed layer deepened from 30-40 m to 45-60 m, although the mixed layer temperature remains similar. These results suggest significant upwelling over the cool region. Figure 1 shows weaker atmospheric forcing over the cool region. The growth of the mixed layer is thus likely a result of a weaker thermocline gradient and weaker upwelling compared to the cooler sector.

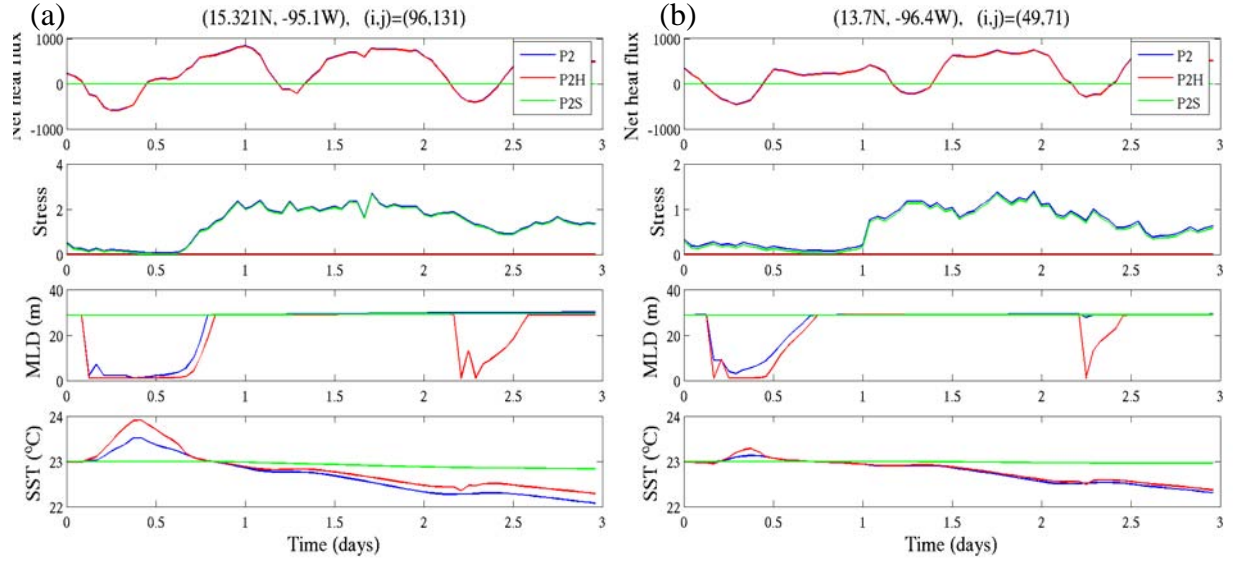


**Figure 3.** Vertical cross-section of water temperature from the AXBT measurements along the flight track. The pink dash lines denote the location and depth of each AXBT drop that provide the data for these cross-section plots. The number in pink by each pink dash line denotes the AXBT drop number. (a) from C-130 Feb 26 2000-2100Z (RF09); and (b) from C-130 Feb 27 2000-2100Z (RF10).

**Effects of wind stress vs. heat flux on mixed layer properties:** The gap event resulted in both enhanced wind forcing and surface heat flux. Simulations were designed to examine the relative importance of surface stress compared to surface heat flux using the forcing from COAMPS



simulations during the gap event. Figure 4 below shows the results for both the cool region and the warm region of the ocean temperature front.

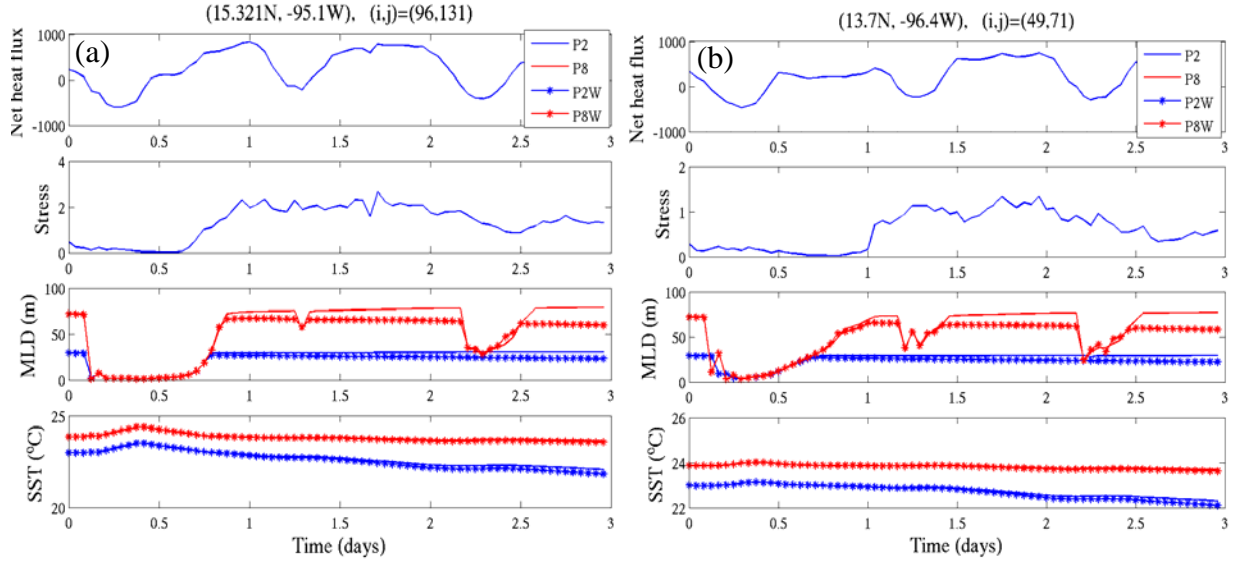


**Figure 4.** Comparison of mixed layer model results using different forcing: forcing of both wind stress and heat flux (P2), heat flux only (P2H), and stress only (P2S). MLD is mixed layer depth. The net heat flux is in  $\text{Wm}^{-2}$  and the stress is in  $\text{Nm}^{-2}$ . The horizontal axis denotes time (in day) from 1200Z 25 February 2004. (a) in the cool region near the coast; (b) in the warm region about 200 km southwest from the mouth of the gulf.

It is seen in Fig. 4 that the warm region has relatively weak surface forcing compared to the cool region because of the longer distance from the jet core of the gap outflow. From simulations with the full COAMPS forcing (P2), the model produced nearly no mixed layer during the daytime with relatively warm SST before the Tehuano. In the cool region, mixed layer depth increased to its maximum immediately following the arrival of the high wind and remain at the maximum for the next two days. Since the Tehuano arrived at night over the warm region, the mixed layer deepened to its maximum before the arrival of Tehuano over the southwest warm region. While mixed layer growth is limited, the mixed layer temperature continued to drop with only slight increase at the presence of negative heat flux during the daytime. The presence of the Tehuano thus maintained entrainment regime in both the warm and cool regions.

Figure 4 clearly indicates heat flux as a dominant factor in mixed layer cooling. For both warm and cool regions, wind stress alone (P2S) results in a nearly constant mixed layer depth and slight cooling of the mixed layer temperature. The results for mixed layer temperature with both shear and heat flux (P2 and P2H) are very similar at night with slight warming and shallowing during the day (expected giving that there is no shear forcing in P2H). Similar results are obtained in the warm region. We thus conclude that the heat flux is a dominant factor in cooling the mixed layer through both direct cooling and enhanced entrainment. The strong wind shear is important in maintaining mixing during the day although the shallowing effect from heat flux is much weakened at the presence of the Tehuano.

**Role of initial condition and upwelling on mixed layer evolution during Tehuano event:** Since the mixed layer model is limited by its prescribed initial condition and upwelling, we designed two more experiment to evaluate the role of both initial condition, particular the thermocline structure, and the role of upwelling. Figure 5 summarizes the results in two plots for both the warm and cool regions.



**Figure 5.** Comparison of COAMPS atmospheric forcing and mixed layer model results for different initial condition and upwelling conditions. The line color represents simulations using different initial conditions and the cases with ‘W’ denote simulations with the specified upwelling. (a) in the cool region near the coast; (b) in the warm region about 200 km southwest from the mouth of the gulf.

The simulation made in P8 used an initial condition derived from the AXBT measurements on Feb 27, 2004 that is over the warm region. The initial mixed layer temperature is at 28 °C, about 5 °C higher than that used in P2. The mixed layer is at 50 m and temperature decrease to 13.5 °C at 140 m below the surface. Compared to the P8 initial condition, the P2 initial profile has mixed layer depth of 20 m with a sharp temperature drop of 9 °C in meter depth. P8 represents a more realistic initial condition for simulations of the warm region. P2 and P8 simulations did not involve upwelling, while P2W and P8W were made with 3 m day<sup>-1</sup> prescribed upwelling. Giving the observed temperature change below the thermocline (Fig. 2), upwelling is likely stronger in the cold region than in the warm region. P2W thus used more realistic forcing in the cool region, while P8 represents realistic forcing for the warm region.

Figure 5 shows that the mixed temperature is not sensitive to the presence of upwelling while the initial conditions had significant impact on both mixed layer depth and temperature. Over the warm regions, the simulated mixed layer temperature is about 1 °C higher and the mixed layer varies between 40 and 60 m during the day and night, respectively. Compared to the observation, the temperature in the warm region is still too cold. This unrealistic result is likely linked to the over-estimated heat flux by COAMPS in this region in addition to the one dimensional assumption.

## IMPACT/APPLICATIONS

The Gulf of Tehuantepec is a natural laboratory for studying air-sea interaction in moderate to high-wind conditions given the frequent occurrence of the gap wind event and the strong spatial variation of ocean temperature. Our research in FY08 examined the ocean response to the Tehuano event using a one dimensional model and surface and radiative forcing from COAMPS. Our results suggest the

importance of using the correct heat flux forcing in the coastal region where strong thermocline limits the growth of the mixed layer by entrainment and surface heat flux becomes a dominant factor in determining SST. We also found that the initial conditions and lower boundary layer conditions are essential factors and have to be specified with variability in the coastal region if a one-dimensional model is to be used.

## **TRANSITIONS**

The results of this project will contribute to establish fully coupled atmosphere/ocean models.

## **RELATED PROJECTS**

Related project is the CBLAST project for surface flux parameterization (Award N0001408WX20782 to NRL Monterey and N0001408WR20137 to NPS).